Advancing TES-Based Phonon Detectors for Sub-GeV Dark Matter

Presented by **Osmond Wen**
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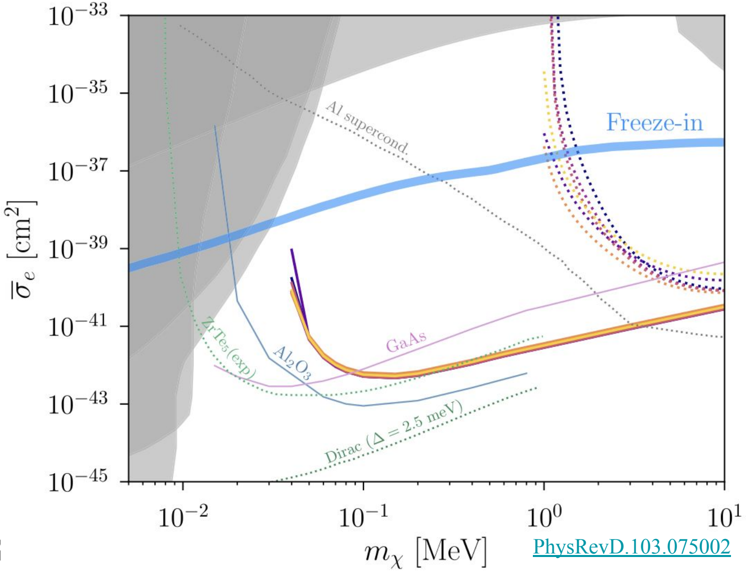
Optimizing sub-GeV DM detection

- **Lower backgrounds**
  - Background reduction with:
    - Underground operation
    - Radio-pure materials
  - Irreducible background?
    - "Low Energy Excess"
- **Lighter targets** for improved kinematic matching
  - C-based substrates for nuclear recoil searches
- **Calibration systematics**
  - Precise NR calibration at low energies

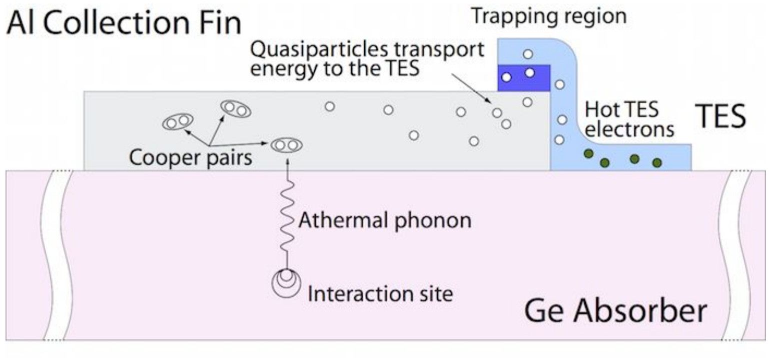
Sensitivity of SiC



PhysRevD.103.075002

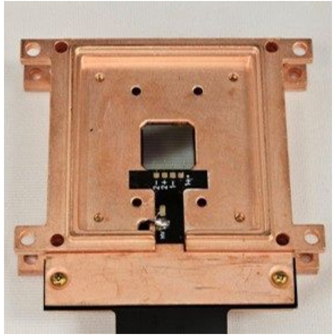
SiC: PhysRevD.103.075002
Diamond: PhysRevD.99.123005

TES-based detectors

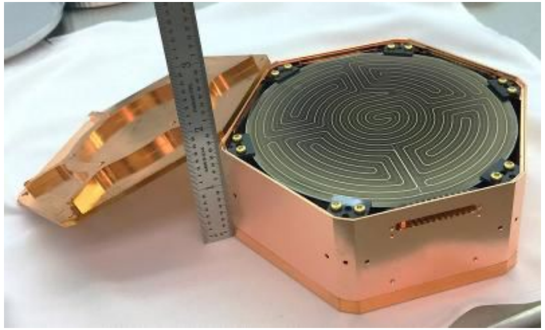


gram-scale

kg-scale



A. Simchony

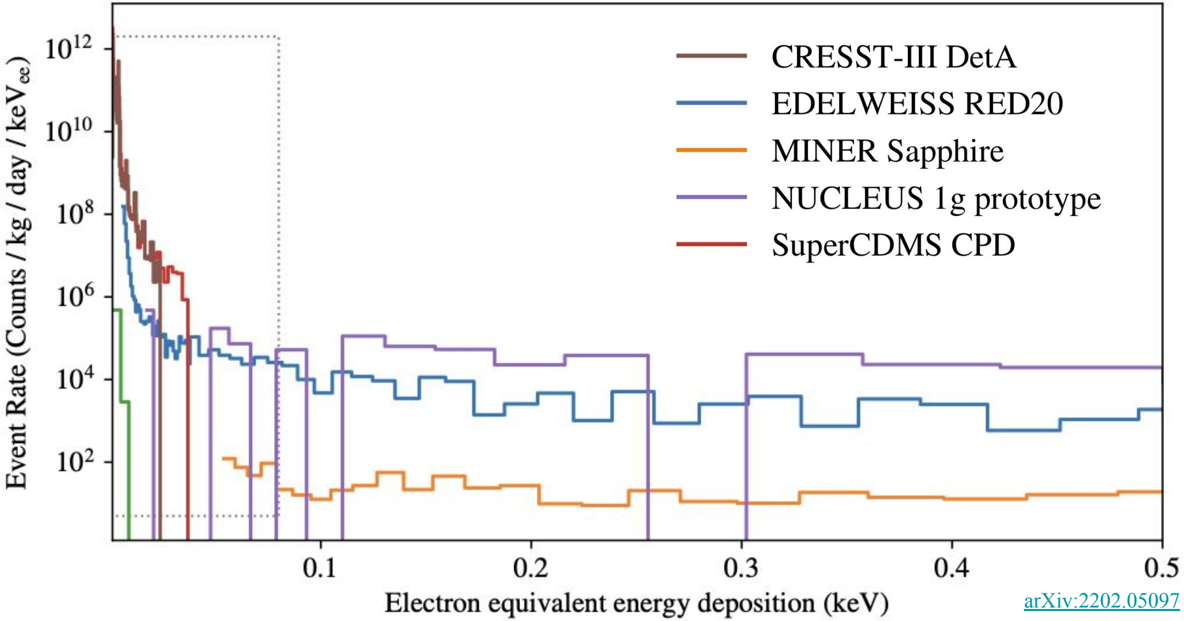


SuperCDMS

- Phonon-mediated detection
- Excellent for low-mass dark matter searches
  - Lower excitation energies leading to low thresholds
  - Excellent energy resolution
- Si, Ge see NTL effect
  - Amplified phonon signal from drifting charges in E-field

What is Low Energy Excess (LEE)?

- Exponentially rising background below 200 eV
- Seen in multiple experiments in diverse technology



arXiv:2202.05097

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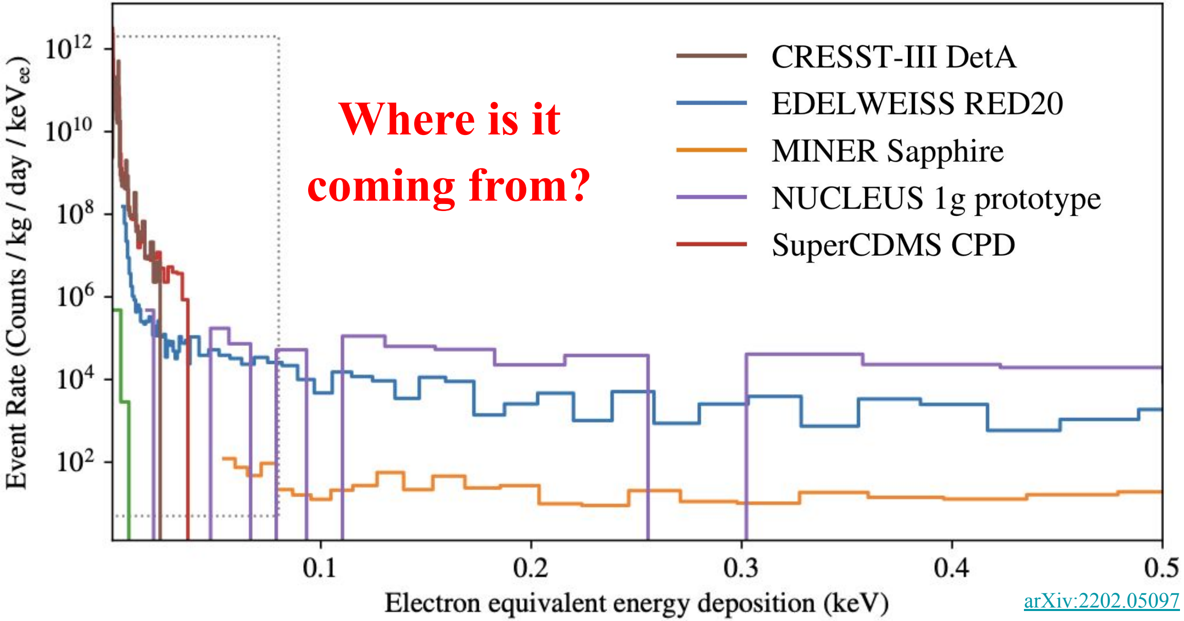
Substrate?

Environment?



arXiv:2202.05097

Leakage?

Housing?

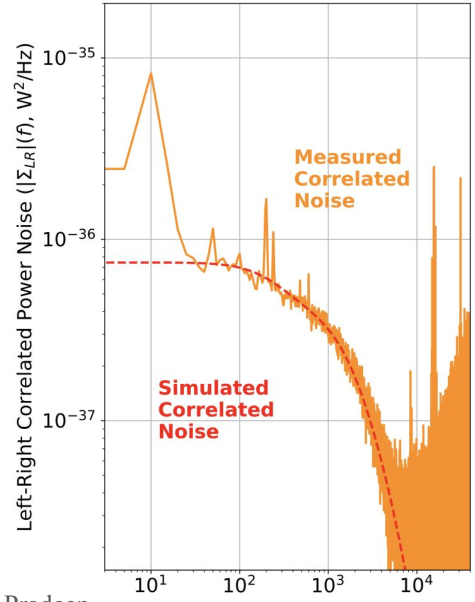
Something else?

Is LEE just a background?

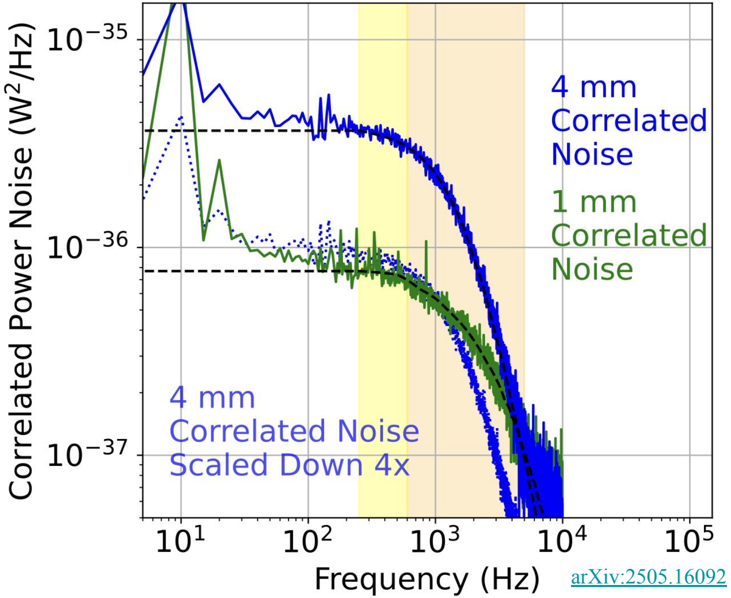
Check out Matt Pyle's talk during Thursday's Low Background RDC 7 session for more details on this study

Can LEE worsen resolution and by extension experimental thresholds?

Reports of correlated shot noise that scales with substrate volume



arXiv:2410.16510

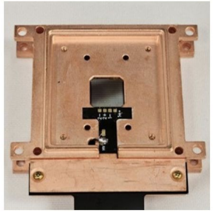


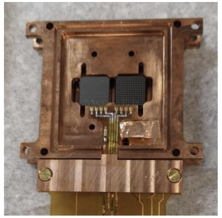
arXiv:2505.16092

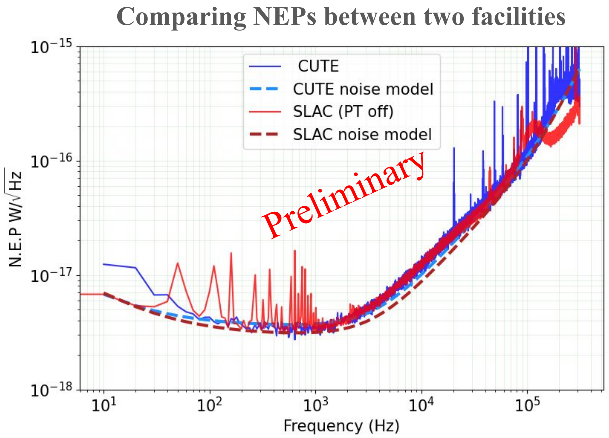
Is LEE just a background?

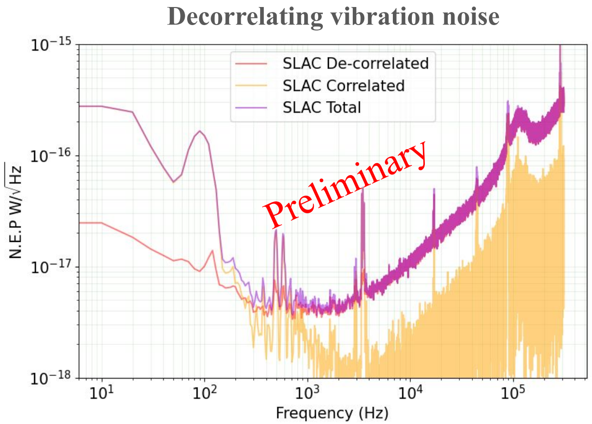
Continued investigation of correlated shot noise: *2 Si detectors with sub-eV resolution, one underground (CUTE) & one above ground (SLAC)*

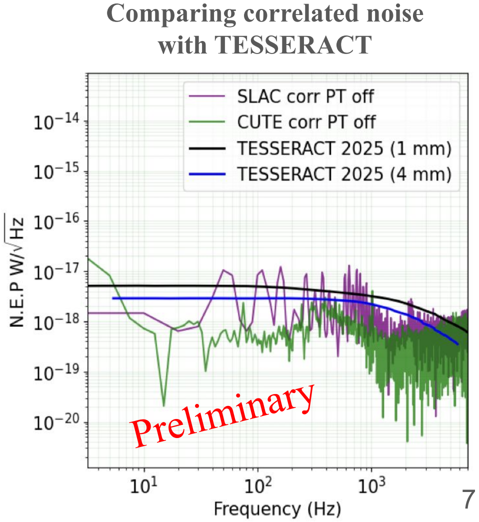
- Energy resolution:
  - **~ 600 meV resolution**
- Noise performance:
  - Measured noise agrees with theoretical models
  - Measured correlated noise appears small









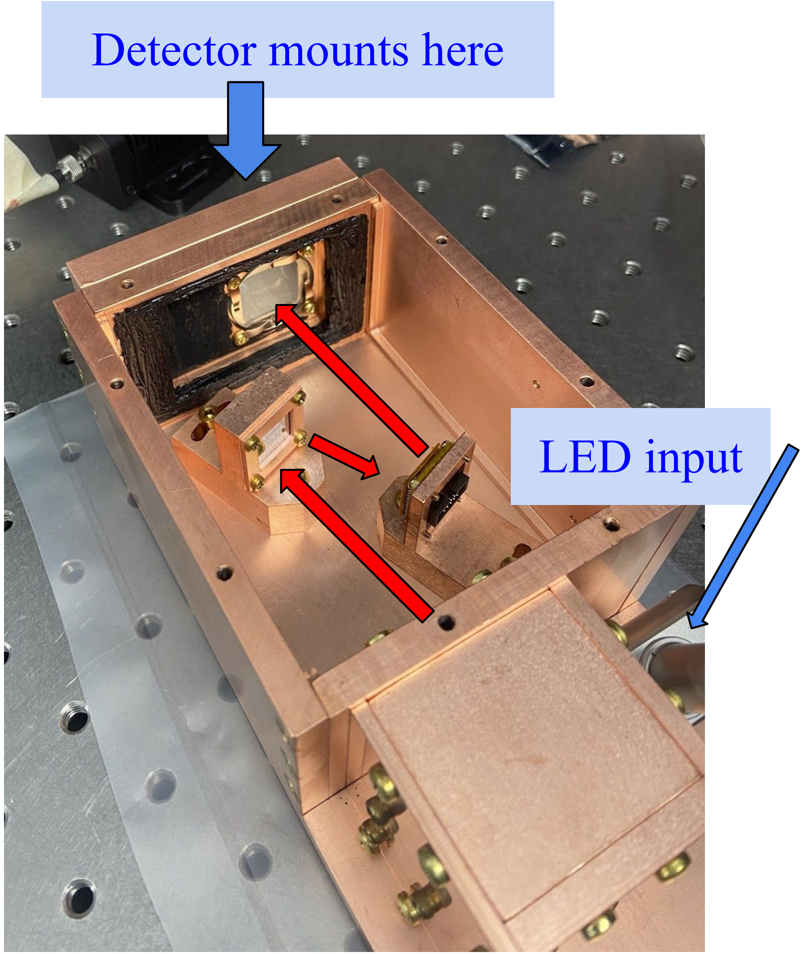


Contributors: K. Kennard, A. Pradeep, H. Fu, Q. Wang, J. Ryan, A. Simchony

LEE is still a limiting background…

The big question: ***How do we get to an LEE-free dark matter search?***

- Surface or bulk events? Stress-induced?
- **Requires excellent position resolution**, but most devices are limited
- **Cryogenic MEMS calibration system for precise beam steering**
    - LED source
    - Rotating MEMS mirror
    - Spot size: ~100 microns
    - 3 cm x 3 cm scan range



Contributors: A. Simchony, H. Fu, A. Pradeep, J. Ryan, T. Aralis. S. Stevens

1.JOM.5.2.024503

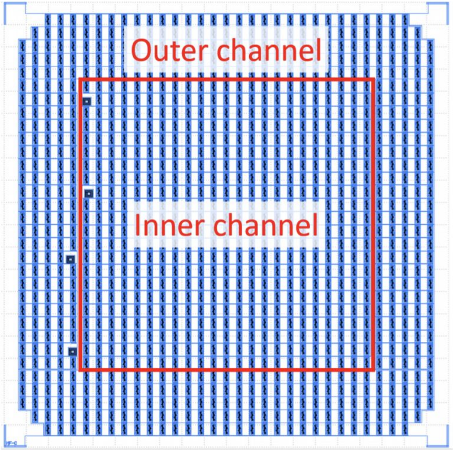
LEE is still a limiting background…

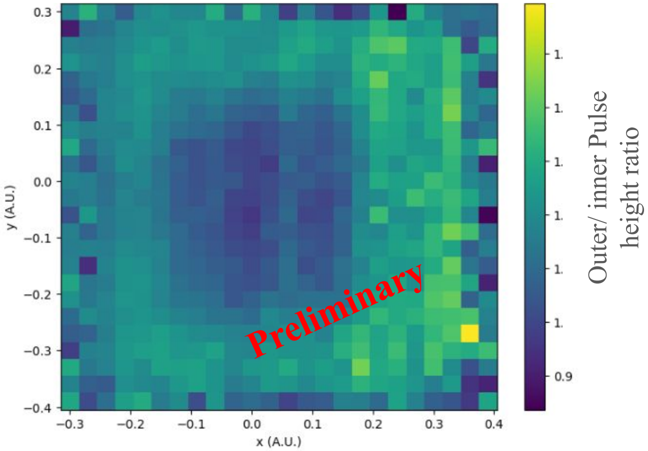
Check out Selby Dang's talk from the RDC 8 Superconducting Sensors session this morning to see how this looks on KIPM detectors

The big question: ***How do we get to an LEE-free dark matter search?***

First results show promising reconstruction of channel map, great potential to achieve fiducialization

More data taking in progress for some exciting LEE studies!





Credit: A. Simchony

Parallel effort: Lowering detector thresholds

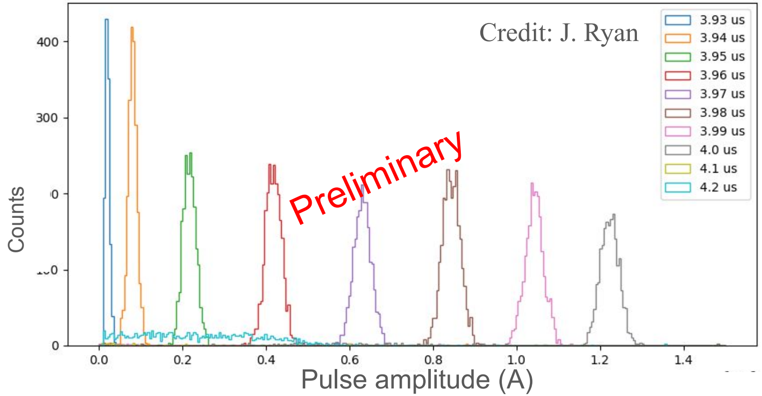
- Low mass nuclei for better scattering kinematics
- Diamond detector fabrication planned this fall
- **First SiC detectors fabricated**
  - ~ 4 eV resolution measured
  - Matches predicted resolution assuming ~30% phonon efficiency
  - No NTL gain: appears to have zero charge mobility

LED wavelength	Resolution in eV	
	Channel A	Channel B
280 nm	3.11	3.91
365 nm	3.55	3.69
625 nm	6.79	6.72

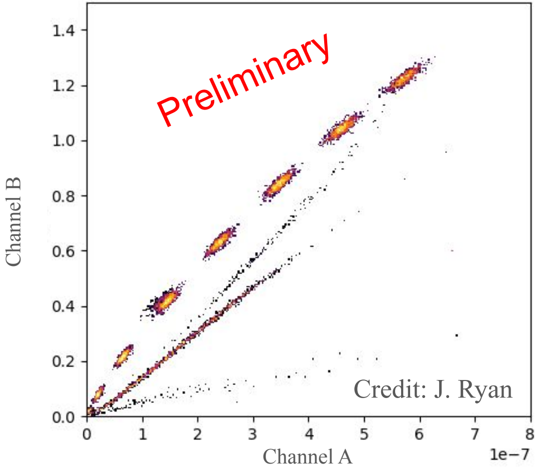
Above band gap

Preliminary

SiC calibration with shot noise



Energy partition between channels

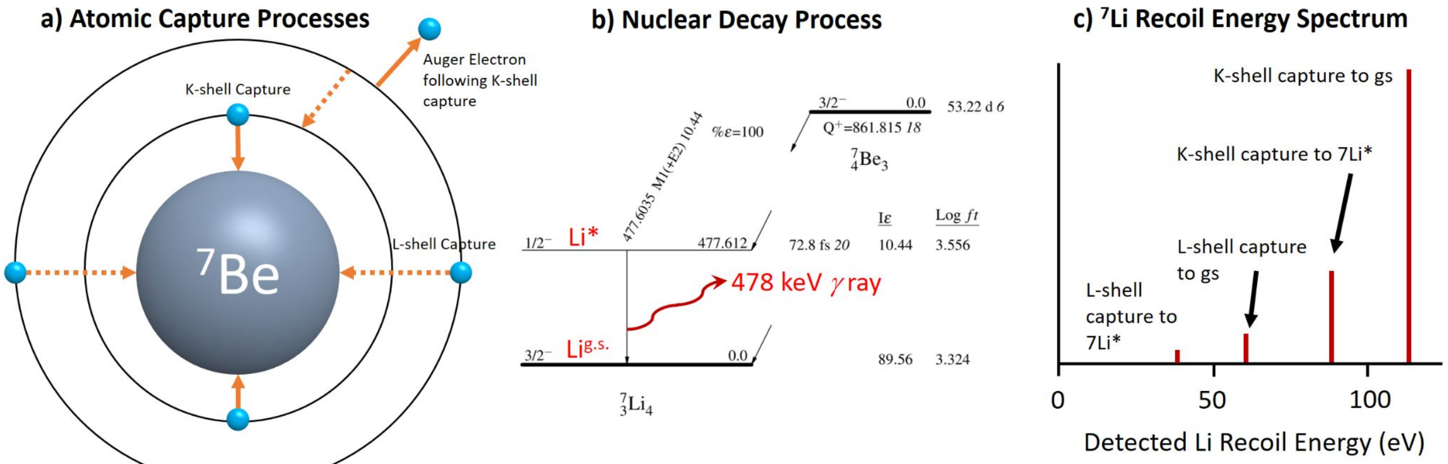


Check out Caitlyn Stone-Whitehead's talk from the RDC 8 Superconducting Sensors session this morning for more details on BeEST

Parallel effort: Precision calibration

Beryllium Electron capture in Superconducting Tunnel junctions (BeEST)

- Implants ^{7}Be in Si substrates; readout with Ta junctions
- Limits sterile neutrino search sensitivity
- Sees **unexplained broadening of NR peaks** compared to photon peaks



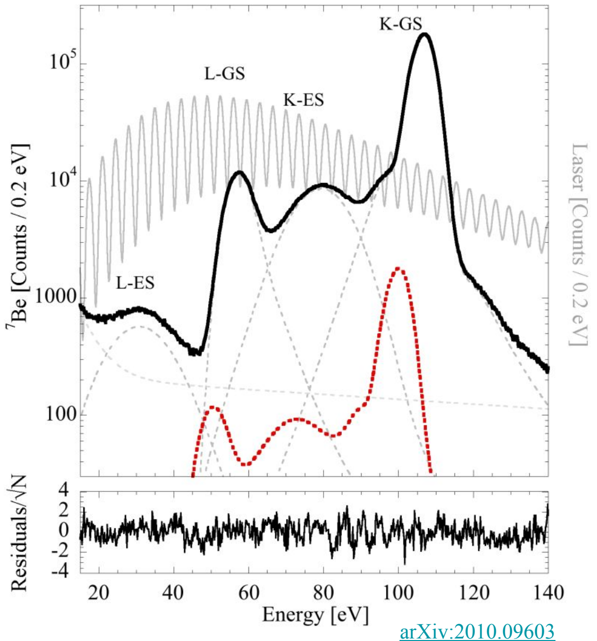
https://beest.mines.edu/scientists/

Contributors: B. Leonardo, A. Anker, B. Mong, J. Ryan, A. Simchony, A. Pradeep

Parallel effort: Precision calibration

Novel physics questions to be explored:

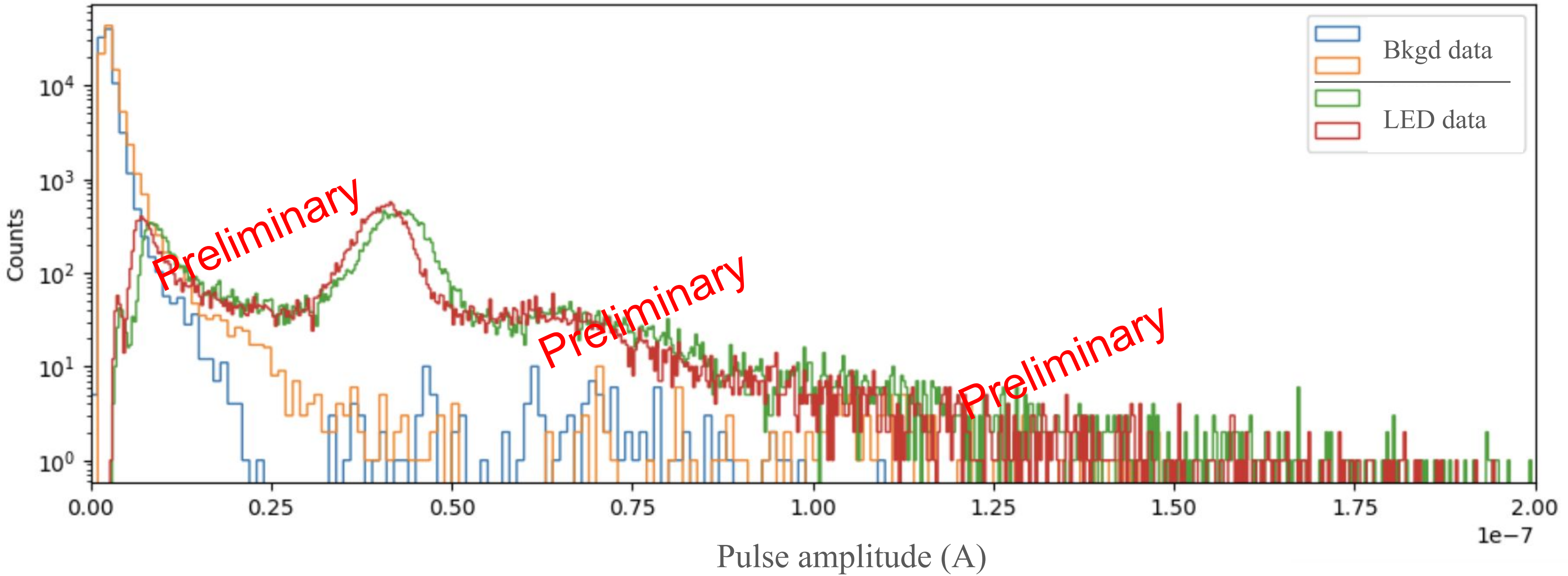
- *Is there a* ***fundamental difference in nuclear recoil and photon-induced quasiparticle dynamics****?*
- *Can we better* ***constrain ionization yield for low energy nuclear recoils*** *for future dark matter searches?*
- *Can we explore* ***alternate low energy calibration options*** *for materials like Si with otherwise limited options?*



arXiv:2010.09603

Contributors: B. Leonardo, A. Anker, B. Mong, J. Ryan, A. Simchony, A. Pradeep

Some VERY preliminary results…



Credit: A. Anker

Summary

- Reducing limiting backgrounds, especially LEE, is a critical challenge in sub-GeV detection
- The DMQIS group:
  - Investigates LEE through spatial reconstruction and noise reduction
  - Develops low-threshold detectors on novel C-based substrates
  - Explores precision calibration and associated systematics in Si detectors with ion implantation